Management Measure 8
Construction Site Erosion, Sediment, and Chemical Control

A. Management Measure

- Prior to land disturbance, prepare and implement an approved erosion and sediment control plan or similar administrative document that contains erosion and sediment control provisions.
- Reduce erosion and, to the extent practicable, retain sediment on-site during and after construction.
- Use good housekeeping practices to prevent off-site transport of waste material and chemicals.
- Minimize application and generation of potential pollutants, including chemicals.

B. Management Measure Description and Selection

1. Description

This management measure is intended to reduce the amount of sediment generated from construction sites (erosion control) and reduce the off-site transport of sediment and construction-related chemicals (sediment and chemical control). This measure is intended to work in concert with the Watershed Protection, New Development Runoff Treatment, and Site Development Management Measures in a comprehensive watershed management program framework.

Several pollutants of concern are associated with construction activities. These pollutants include sediment; pesticides (insecticides, fungicides, herbicides, and rodenticides); fertilizers used for vegetative stabilization; petrochemicals (oils, gasoline, and asphalt degreasers); construction chemicals such as concrete products, sealers, and paints; wash water associated with these products; paper; wood; garbage; and sanitary waste (Washington State Department of Ecology, 1991).

The variety of pollutants present at a site and the severity of their effects are dependent on a number of factors:

The nature of the construction activity. For example, potential pollution associated with fertilizer use might be greater along a highway or at a housing development than it would be at a shopping center development because highways and housing developments usually have greater landscaping requirements.

The physical characteristics of the construction site. Most pollutants generated at construction sites are carried to surface waters by runoff. Therefore, the factors that affect runoff volume, such as the amount, intensity, and frequency of rainfall; soil infiltration rates; surface roughness; slope length and steepness; and denuded area, also affect pollutant loadings.

The proximity of surface waters to the nonpoint pollutant source. As the distance separating pollutant-generating activities from surface waters decreases, the likelihood of water quality impacts increases.

The following section is an expanded discussion of the pollutants of concern that can be generated by and released from construction activities.

a. Sediment

Runoff from construction sites is by far the largest source of sediment in urban areas under development. Soil erosion removes more than 90 percent of sediment by weight in urbanizing areas where most construction activities occur (Canning, 1988). Table 5.1 illustrates some of the sediment loading rates associated with construction activities across the United States. As shown in Table 5.1, erosion rates from natural areas such as undisturbed forested lands are typically less than 1 ton/acre/year, whereas erosion from construction sites ranges from 7.2 to 500 tons/acre/year.

Loss of sediment can cause impacts both on and off the construction site. On-site loss of soil reduces or eliminates the remaining soil's ability to provide nutrients, regulate water flow, and combat pests and diseases. First, losses of nutrients and nutrient holding capacity result in a less fertile environment for lawns and plants. Second, lost organic matter results in increased soil density and compaction, which can reduce the available water-holding capacity on-site. This reduction results in poorer plant growth and reduced infiltration of fertilizers and pesticides, which contribute to the transport of these chemicals by runoff into nearby lakes and streams. Third, organic matter is a food source and habitat for beneficial microorganisms and invertebrates. If organic matter is lost, the soil's natural ability to combat outbreaks of pests and diseases is reduced (SQI, 2000).

Eroded sediment from construction sites causes many problems in coastal areas, including adverse impacts on water quality, critical habitats, submerged aquatic vegetation beds, recreational activities, and navigation (APWA, 1991). Water quality impacts include unwanted biological growth, caused by excess nitrogen and phosphorus, and increased turbidity. Eroded sediment can also build up in stream channels and lower flow capacity, resulting in more frequent flooding in areas that never or rarely flooded in the past. Reducing the incidence of flooding can also be beneficial in alleviating the financial burden of cleaning up sediment-damaged areas (SQI, 2000). Finally, excessive erosion and sedimentation can reduce the capacity of reservoirs.

Case Study: Soil Erosion from Two Small Construction Sites in Dane County, Wisconsin

Most construction regulations require sites with more than 5 acres disturbed to have some type of erosion control plan. Sites that are less than 5 acres typically require minimal erosion control measures. To evaluate the significance of erosion on sites less than 5 acres as a source of sediment to surface waters, two small construction sites (less than 5 acres each) in Dane County, Wisconsin, were studied (USGS, 2000).

Results indicate that small construction sites are potential sources of high amounts of erosion and that sediment loads from the active construction phase are significantly higher than those during the preconstruction and postconstruction periods. These sediment loads were dramatically reduced when mulching and seeding were used to control erosion. The results of this study support the need for erosion control plans for small construction sites.

The Miami River in Florida has been severely affected by pollution associated with upland erosion. This watershed has undergone extensive urbanization, which has included the construction of many commercial and residential buildings, over the past 50 years. Sediment deposited in the Miami River channel contributes to the severe water quality and navigation problems of this once-thriving waterway, as well as to Biscayne Bay (SFWMD, 1988).

Table 5.1: Erosion and sediment associated with construction (USEPA, 1993).

Location	Problem	Reference
Franklin County, Florida	Sediment yield (ton/ac/yr): Forest < 0.5 Rangeland < 0.5 Tilled 1.4 Construction site 30 Established urban < 0.5	Franklin County, Florida, 1987
Wisconsin	Erosion rates range from 30 to 200 ton/ac/yr (10 to 20 times those of cropland).	Wisconsin Legislative Council, 1991
Washington, DC	Erosion rates range from 35 to 45 ton/ac/yr (10 to 100 times greater than agriculture and stabilized urban land uses).	MWCOG, 1987
Anacostia River Basin, Maryland and Washington, DC	Sediment yields from portions of the Anacostia Basin have been estimated at 75,000 to 132,000 ton/yr. Total basin acreage = 112,640 acres.	U.S. Army Corps of Engineers, 1990
Anacostia River Basin, Maryland and Washington, DC	Erosion rates range from 7.2 to 100.8 ton/ac/yr. Total basin acreage = 112,640 acres.	USGS, 1978
Washington	Erosion rates range from 50 to 500 ton/ac/yr. Natural erosion rates from forests or well-sodded prairies are 0.01 to 1.0 ton/ac/yr.	Washington State Department of Ecology, 1989
Alabama North Carolina Louisiana Oklahoma Georgia Texas Tennessee Pennsylvania Ohio Kentucky	1.4 million tons eroded per year. 6.7 million tons eroded per year. 5.1 million tons eroded per year. 4.2 million tons eroded per year. 3.8 million tons eroded per year. 3.5 million tons eroded per year. 3.3 million tons eroded per year. 3.1 million tons eroded per year. 3.0 million tons eroded per year. 3.0 million tons eroded per year.	Woodward Clyde, 1991

b. Pesticides

Insecticides, rodenticides, and herbicides are used on construction sites to improve human health conditions, reduce maintenance and fire hazards, and curb the growth of weeds and woody plants. Common pesticides employed include synthetic, relatively water-insoluble chlorinated hydrocarbons, organophosphates, carbamates, and pyrethrins. Overapplication of pesticides on revegetated areas can lead to contamination of soils and subsequent contamination of surface and ground water. The use of pesticides is controlled by federal or state regulations.

c. Petroleum products

Petroleum products used during construction include fuels and lubricants for vehicles, power tools, and general equipment maintenance. Specific petroleum pollutants include gasoline, diesel oil, kerosene, lubricating oils, and grease. Asphalt paving can be particularly harmful because it releases various oils after application until fully cured (NCHRP, 2000).

d. Fertilizers

Fertilizers are used on construction sites when revegetating graded or disturbed areas. Fertilizers contain nitrogen and phosphorus, which in large doses can adversely affect surface water quality, causing eutrophication.

e. Solid wastes

Trees and shrubs removed during land clearing contribute to the load of solid wastes generated during construction activities. Other common wastes are wood and paper from packaging and building materials, scrap metals, sanitary wastes, rubber, plastic and glass, and masonry and asphalt products. Improper disposal of food containers, paint canisters, cigarette packages, leftover food, and aluminum foil also contributes solid wastes to the construction site.

f. Construction chemicals

There are several sources of chemicals at construction sites. For example, chemicals like paints, acids for cleaning masonry surfaces, cleaning solvents, asphalt products, soil additives used for stabilization, and concrete-curing compounds might be used on construction sites and carried off in runoff. Other pollutants, such as wash water from concrete mixers, acid and alkaline solutions from exposed soil or rock, and alkaline-forming natural elements, might also be present and contribute to nonpoint source pollution. Improperly stored construction materials, such as pressure-treated lumber or solvents, can lead to leaching of pollutants to surface water and ground water. Persons disposing of construction chemicals should follow all applicable state and local laws, which may require disposal by a licensed waste management firm.

Improper fueling and servicing of vehicles can lead to significant quantities of petroleum products being dumped onto the ground. These pollutants can then be washed off the site in urban runoff, even when proper erosion and sediment controls are in place. Pollutants carried in solution in runoff or attached to sediments might not be adequately controlled by erosion and sediment control practices (Washington Department of Ecology, 1991). Oils, waxes, and water-insoluble pesticides can form surface films on water and solid particles. Oil films can also concentrate water-soluble insecticides. These pollutants can be nearly impossible to control once present in runoff other than by the use of very costly water treatment facilities (Washington Department of Ecology, 1991).

After spill prevention, one of the best methods to control petroleum pollutants is to retain the sediments that contain the chemicals on the construction site through use of erosion and sediment control practices. Improved maintenance and safe storage facilities reduce the chance of contaminating a construction site. One of the greatest concerns related to use of petroleum products is the method for waste disposal. Dumping petroleum product wastes into sewers and other drainage channels is illegal and could result in fines or site closure.

g. Contaminated soils

Contaminated soils can be encountered during excavation activities that uncover previously known or unknown site contamination. Also, new contamination can result from a spill or leak of a hazardous material used at the construction site (a release from a material or waste storage area). If previously unknown contamination is encountered, the nature of that contamination might not be immediately known. Sampling and analysis will be required to determine what types of contaminants are present and, therefore, how the contaminated soil needs to be handled. Furthermore, extensive investigations might need to be implemented to determine the extent of contamination present.

2. Management Measure Selection

This management measure was selected to minimize sediment being transported outside the perimeter of a construction site by reducing erosion and retaining sediment on-site. Additionally, the management measure was selected because construction activities have the potential to contribute to increased loadings of toxic substances and nutrients to waterbodies. Various states and local governments regulate the control of sediment and chemicals on construction sites through spill prevention plans, erosion and sediment control plans, or other administrative devices. The practices provided herein are commonly used and well described in handbooks and guidance manuals, and they have been shown to be both economical and effective.

The measures were selected for the following reasons:

- Setting numeric load reduction goals is generally not practical; sediment and other pollutant loadings from exposed areas vary greatly, and some sediment loss is usually inevitable.

- Erosion and sediment control plans (ESCs) and specifications are required by many state and local governments to accomplish the performance goals for this measure. These ESCs specify designs and proper placement of practices, including soil stabilization, and procedures for installation and maintenance of practices, and they have been proven to be effective when followed at construction sites.

Case Study: Eugene, Oregon's goals for erosion and sediment control on construction sites

The City of Eugene, Oregon, requires all construction sites to employ, to the maximum extent feasible, management practices that meet a specified set of outcomes, including the following (NRDC, 1999):

- No deposit or discharge of sediment onto adjacent properties or into waterbodies.
- No degradation of waterbodies due to the removal of vegetation.
- No discharge or runoff containing construction-related contaminants into the city's runoff conveyance system or related natural resources.
- No deposit of construction-related material exceeding 0.5 cubic foot for every 1,000 square feet of lot size onto public rights-of-way and private streets and into the city's runoff conveyance system and related natural resources.

- Current practice typically relies on a set of practices selected based on site-specific conditions.
- The combined effectiveness of erosion and sediment controls in systems is not easily quantified.

C. Management Practices

1. Erosion and Sediment Control Programs

a. Prepare erosion and sediment control plans

In many municipalities, erosion and sediment control plans are required under ordinances enacted to protect water resources (Table 5.2). These plans describe how a contractor or developer will reduce soil erosion and contain and treat runoff that is carrying eroded sediments. Plans typically include descriptions and locations of soil stabilization practices, perimeter controls, and runoff treatment facilities that will be installed and maintained before and during construction activities. In addition to special area considerations, the full ESC plan review inventory should include

- Topographic and vicinity maps.
- Site development plan.
- Construction schedule.
- Erosion and sedimentation control plan drawings.
- Detailed drawings and specifications for practices.
- Design calculations.
- Vegetation plan.

Table 5.2: ESC plan requirement for selected states (Adapted from USEPA, 1993; Environmental Law Institute, 1998).

State	General Requirements for ESC Plan
Delaware	ESC plans required for sites over 5,000 ft^2. Temporary or permanent stabilization must occur with 14 days of disturbance.
Florida	ESC plans required on all sites that need a runoff management permit.
Georgia	ESC plan required for all land-disturbing activities.
Indiana	ESC plan required for sites over 5 acres.
Maine	ESC plans required for sites adjacent to a wetland or waterbody. Stabilization must occur at completion or if no construction activity is to occur for 7 days. If temporary stabilization is used, permanent stabilization must be implemented within 30 days.
Maryland	ESC plans required for sites over 5,000 ft^2 or 100 yd^3.
Michigan	ESC plans required for sites over 1 acre or within 500 ft of a waterbody. Permanent stabilization must occur within 15 days of final grading. Temporary stabilization is required within 30 days if construction ceases.
Minnesota	ESC plans required for land development over 1 acre.
New Jersey	ESC plans required for sites over 5,000 ft^2.
North Carolina	ESC plans required for sites over 1 acre. Controls must retain sediment on-site. Stabilization must occur within 30 days of completion of any phase of development.
Ohio	ESC plans required for sites over 5 acres. Permanent stabilization must occur within 7 days of final grading or when there is no construction activity for 45 days.
Oklahoma	ESC plans required for sites over 5 acres.
Pennsylvania	ESC plans required for all sites, but the state reviews only plans for sites over 25 acres. Permanent stabilization must occur as soon as possible after final grading. Temporary stabilization is required within 70 days if construction ceases for more than 30 days. Permanent stabilization is required if the site will be inactive for more than 1 year.
South Carolina	ESC plans required for all sites unless specifically exempted. Perimeter controls must be installed. Temporary or permanent stabilization is required for topsoil stockpiles and all other areas within 7 days of disturbance.
Virginia	For areas within the jurisdiction of the Chesapeake Bay Preservation Act, no more land is to be disturbed than necessary for the project. Indigenous vegetation must be preserved to the greatest extent possible.
Washington	ESC provisions are incorporated into the state runoff management plan.
Wisconsin	ESC plans required for all sites over 4,000 ft^3. Temporary or permanent stabilization is required within 7 days.

Brown and Caraco (1997) identified several general objectives that should be addressed in an effective ESC plan:

- *Minimize clearing and grading*. Clearing and grading should occur only where absolutely necessary to build and provide access to structures and infrastructure. This approach reduces earth-working and ESC control costs by as much as $5,000 per acre (Schueler, 1995). Clearing should be done immediately before construction, rather than leaving soils exposed for months or years (SQI, 2000).

- *Protect waterways and stabilize drainageways*. All natural waterways within a development site should be clearly identified before construction activities begin. Clearing should generally be prohibited in or adjacent to waterways. Sediment control practices such as check dams might be needed to stabilize drainageways and retain sediment on-site.

- *Phase construction to limit soil exposure*. Construction phasing is a process by which only a portion of the site is disturbed at any one time to complete the needed building in that phase. Other portions of the site are not cleared and graded until exposed soils from the earlier phase have been stabilized and the construction nearly completed.

- *Stabilize exposed soils immediately*. Seeding or other stabilization practices should occur as soon as possible after grading. In colder climates, a mulch cover is needed to stabilize the soil during the winter months when grass does not grow or grows poorly.

- *Protect steep slopes and cuts*. Wherever possible, clearing and grading of existing steep slopes should be completely avoided. If clearing cannot be avoided, practices should be implemented to prevent runoff from flowing down slopes.

- *Install perimeter controls to filter sediments*. Perimeter controls are used to retain sediment-laden runoff or filter it before it exits the site. The two most common perimeter control options are silt fences and earthen dikes or diversions.

- *Employ advanced sediment-settling controls*. Traditional sediment basins are limited in their ability to trap sediments because fine-grained particles tend to remain suspended and the design of the basin themselves is often simplistic. Sediment basins can be designed to improve trapping efficiency through the use of perforated risers; better internal geometry; the installation of baffles, skimmers, and other outlet devices; gentler side slopes; and multiple-cell construction.

ESC plans ensure that provisions for control measures are incorporated into the site planning stage of development, help to reduce the incidence of erosion and sediment problems, and improve accountability if a problem occurs. An effective plan for runoff management on construction sites controls erosion, retains sediments on-site to the extent practicable, and reduces the adverse effects of runoff. Climate, topography, soils, drainage patterns, and vegetation affect how erosion and sediment should be controlled on a site (Washington State Department of Ecology, 1989).

An effective ESC plan includes both structural and nonstructural controls. Nonstructural controls address erosion control by decreasing erosion potential, whereas structural controls are both preventive and mitigative because they control erosion and sediment movement. Typical nonstructural erosion controls include

- Planning and designing the development within the natural constraints of the site.
- Minimizing the area of bare soil exposed at one time (phased grading).
- Providing stream crossing areas for natural and man-made areas.
- Stabilizing cut-and-fill slopes caused by construction activities.

Structural controls include

- Installing perimeter controls.
- Mulching and seeding exposed areas.
- Installing sediment basins and traps.
- Using silt fences or filter fabrics.

Some erosion and soil loss is unavoidable during land-disturbing activities. Although proper siting and design help prevent areas prone to erosion from being developed, construction activities invariably produce conditions where erosion can occur. To reduce the adverse impacts associated with construction, the construction management measure suggests a system of nonstructural and structural erosion and sediment controls for incorporation into an ESC plan. Erosion controls have distinct advantages over sediment controls. Erosion controls reduce the amount of sediment transported off-site, thereby reducing the need for sediment controls. When erosion controls are used in conjunction with sediment controls, the size of the sediment control structures and associated maintenance may be reduced, decreasing the overall treatment costs (SWRPC, 1991).

b. Provide education and training opportunities for designers, developers, and contractors

One of the most important factors determining whether erosion and sediment controls will be properly installed and maintained on a construction site is the knowledge and experience of the contractor. Many communities require certification for key on-site employees who are responsible for implementing the ESC plan. Certification can be accomplished through municipally sponsored training courses; more informally, municipalities can hold mandatory preconstruction or prewintering meetings and conduct regular and final inspection visits to transfer information to contractors (Brown and Caraco, 1997). Information that should be covered in training courses and meetings includes the importance of ESC for water quality

Case Study: Contractor/Developer Certification Programs in Delaware and Maine

Delaware requires that at least one person on any construction project be formally certified. The Delaware program requires certification for any foreman or superintendent who is in charge of on-site clearing and land-disturbing activities for sediment and runoff control associated with a construction project. Responsible personnel are required to obtain certification by completing a Department of Natural Resources and Environmental Control-sponsored or approved training program. All applicants seeking approval of a sediment and runoff plan must certify that all personnel involved in the construction project will have a certificate of attendance at a Department-sponsored or approved training course before initiation of any land-disturbing activity (Delaware DNREC, no date). A description of this certification requirement is provided at the DNREC web site at *www.dnrec.state.de.us/newpages/ssregs14.htm*.

The Maine Department of Environmental Protection offers the Voluntary Contractor Certification Program (VCCP), which is a nonregulatory, incentive-driven program to broaden the use of effective erosion control techniques. The VCCP is open to any contractor who is involved with soil disturbance activities, including filling, excavating, landscaping, and other types of earthworks. For initial certification, the program requires attendance at two 6-hour training courses and the successful completion of a construction site evaluation. To maintain certification, a minimum of one 4-hour continuing education course within every 2-year period thereafter is required. Local soil and water conservation district personnel will complete construction site evaluations during the construction season. Certifications are valid until December 31 of the second year after issuance. Certification entitles the holder to advertise services as a "DEP Certified Contractor" (MDEP, 1999). More information about this program is provided on the MDEP web site at *janus.state.me.us/dep/blwq/training/is-vccp.htm*.

Case Study: The California Department of Transportation's Storm Water Management Plan

The California Department of Transportation (Caltrans) operates one of the most comprehensive storm water drainage systems in the United States. It has recently undertaken a multifaceted program to investigate and address pollutant load reduction in California's storm water runoff. To improve storm water management, Caltrans created the Storm Water Task Force (SWTF) to monitor, train, and educate its employees and hired contractors about pollution prevention measures. The SWTF's goals are to raise awareness and to change work habits so that Caltrans employees can more effectively address storm water issues. The SWTF uses the following techniques to accomplish their goals (Borroum et al., 2000):

– Inspecting projects and facilities for compliance with erosion, sediment control, and waste management requirements.

– Providing classroom and on-the job training and consulting.

– Publishing a monthly storm water bulletin for employees and state and local regulatory agencies.

– Reviewing storm water pollution prevention plans for construction sites.

– Providing feedback on how well methods work and what improvements could be made to improve performance.

– Preparing specialized training materials, such as videos and model pollution prevention plans.

– Providing input for storm water guidance manuals and water pollution control specifications for highway design and construction.

protection; developing and implementing ESC plans; the importance of proper installation, regular inspection, and diligent maintenance of ESC practices; and recordkeeping for inspections and maintenance activities.

c. Establish plan review and modification procedures

ESC plans should be flexible to account for unexpected events that occur after the plans have been approved, including

– Discrepancies between planned and as-built grades.
– Weather conditions.
– Altered drainage.
– Unforeseen construction requirements.

Changes to an ESC plan should be made based on regular inspections that identify whether the ESC practices were appropriate or properly installed or maintained.

d. Assess ESC practices after storm events

Inspecting an ESC practice after storm events shows whether the practice was installed or maintained properly. Such inspections also show whether a practice requires cleanout, repair, reinforcement, or replacement with a more appropriate practice. Inspecting after storms is the best way to ensure that ESC practices remain in place and effective at all times during construction activities.

e. Ensure ESC plan implementation

Because funding for ESC programs is not always dedicated, budgetary and staffing constraints may thwart effective program implementation. Brown and Caraco (1997) recommend several management techniques to ensure that ESC programs are properly administered:

- Local leadership committed to the ESC program.
- Redeployment of existing staff from the office to the field or training room.
- Cross-training of local review and inspection staff.
- Submission of erosion prevention elements for early planning review.
- Prioritization of inspections based on erosion risk.
- Requirement of designers to certify the initial installation of ESC practices.
- Investment in contractor certification and private inspector programs.
- Use of public-sector construction projects to demonstrate effective ESC controls.
- Enlistment of the talents of developers and engineering consultants in the ESC program.
- Revision and update of the local ESC manual.

An allowance item that acts as an additional "insurance policy" for complying with the erosion and sediment control plan can be added to bid or contract documents (Deering, 2000a). This allowance covers costs to repair storm damage to erosion and sediment control measures as specified in the erosion and sediment control plan. This allowance does not cover storm damage to property that is not related to the erosion and sediment control plan, because this would be covered under traditional liability insurance. Damage caused by severe and continuous rain events, windblown objects, fallen trees or limbs, or high-velocity, short-term rain events on steep slopes and existing grades would be covered by the allowance, as would deterioration from exposure to the elements or excessive maintenance for silt removal. The contractor is responsible for being in compliance with the erosion and sediment control plan by properly implementing and maintaining all specified measures and structures. The allowance does not cover damage to practices caused by improper installation or maintenance.

A study by University of North Carolina researchers measured the effects of erosion and sediment control regulations, inspections, and enforcement on steam biological condition at 17 construction sites in central North Carolina (Reice and Andrews, 2000). At each site, upstream, downstream, and at-site samples were taken before construction began, during the peak land disturbance, and after the project was completed and released by the regulatory agency. Benthic and fish communities were sampled in addition to several water chemistry variables and leaf litter decomposition rates. The researchers found the following results:

- Virtually all at-site samples showed some degradation relative to upstream controls.

- Impacts at sites downstream from construction sites were highly variable.

- Degree of degradation was significantly affected by enforcement activities: stronger enforcement resulted in less environmental impact on the streams.

- The stringency of the erosion and sediment control regulations proved unimportant compared to enforcement.

They concluded that staffing, workload, attitudes, and enforcement activities strongly influenced downstream conditions.

2. Erosion Control Practices

Erosion controls are used to reduce the amount of sediment removed during construction and to prevent sediment from entering runoff. Erosion control is based on two main concepts: (1) disturb the smallest area of land possible for the shortest period of time, and (2) stabilize disturbed soils to prevent erosion from occurring. Table 5.3 shows cost and effectiveness information for several erosion control practices.

a. Schedule projects so clearing and grading are done during the time of minimum erosion potential

Often a project can be scheduled during the time of year that the erosion potential of the site is relatively low. In many parts of the country, there is a certain period of the year when erosion potential is relatively low and construction scheduling could be very effective. For example, in the Pacific region if construction can be completed during the 6-month dry season (May 1 to October 31), temporary erosion and sediment controls might not be needed. In addition, in some parts of the country erosion potential is very high during certain parts of the year such as the spring thaw in northern and high-elevation areas. During that time of year, snowmelt generates a constant runoff that can erode soil. In addition, construction vehicles can easily turn the soft, wet ground into mud, which is more easily washed off-site. Therefore, in the north, limitations should be placed on clearing and grading during the spring thaw (Goldman et al., 1986).

b. Phase construction

Construction site phasing involves disturbing only small portions of a site at a time to prevent erosion from dormant parts (CWP, 1997c). Grading activities and construction are completed and soils are effectively stabilized on one part of the site before grading and construction commence at another. This is different from the more traditional practice of construction site sequencing, in which construction occurs at only one part of the site at a time but site grading and other site-disturbing activities typically occur all at once, leaving portions of the disturbed site vulnerable to erosion. Construction site phasing must be incorporated into the overall site plan early on. Elements to consider when phasing construction activities include (CWP, 1997c)

- Managing runoff separately in each phase.

- Determining whether water and sewer connections and extensions can be accommodated.

- Determining the fate of already completed downhill phases.

– Providing separate construction and residential accesses to prevent conflicts between residents living in completed stages of the site and construction equipment working on later stages.

Table 5.3: Cost and effectiveness for selected erosion control practices.

Practice	Percent TSS Removal	Effectiveness References	Cost (2001 Dollars[a])	Cost References
Earth dike	NA	NA	Small dikes: \$2.50–\$6.50/linear ft Large dikes: \$2.50/yd^3	NAHB, 1995; SWRPC, 1991
Pipe slope drain	NA	NA	\$5/linear ft for flexible PVC pipe; inlet and outlet structures additional	NAHB, 1995
Terraces	1%–12% slope: 70% less erosion 12%–18% slope: 60% less erosion 18%–24% slope: 55% less erosion	USEPA, 1993	Average: \$6/linear ft Range: \$1.20–\$14.50/linear ft	USEPA, 1993
Check dams	NA	NA	\$100/dam (constructed of rock)	NAHB, 1995
Seeding	Average: 90% Range: 50%–100%	USEPA, 1993	Average: \$0.10/yd^2 Range: \$0.05–\$0.25/yd^2 Maintenance costs: 15%–25% of installation costs	USEPA, 1993
Mulching	53%–99.8% reduction of soil loss 24%–78% reduction in water velocity	Harding, 1990	Average: \$0.38/yd^2 Range: \$0.21–\$0.87/yd^2	USEPA, 1993
Sodding	98–99%	USEPA, 1993	Average: \$2.20/yd^2 Range: \$1.10–\$12/yd^2 Maintenance costs: 5% of installation costs	USEPA, 1993
Erosion control blankets	70% wheat straw/30% coconut fiber: 98.7% Straw: 89.2%–98.6% Curled wood fiber: 28.8%–93.6% Jute mats: 60.6% Synthetic fiber: 71.2% Nylon monofilament: 53.0%	CWP, 1997a	Biodegradable materials: \$0.50–\$0.57/yd^2 Permanent materials: \$3.00–\$4.50/yd^2 Staples: \$0.04–\$0.05/staple	Erosion Control Systems, Inc., personal communication, March 14, 2001
Chemical stabili-zation	PAM: 77–93%	Rosa-Espinosa et al., No date	PAM: \$1.30–\$38.50/lb	Entry and Sojka, 1999; Sojka and Lentz, 1996

[a]Costs adjusted for inflation using the Consumer Pricing Index (BLS, 2001).

A comparison of sediment loss from a typical development and from a comparable phased project showed a 42 percent reduction in sediment export in the phased project (CWP, 1997c).

Phasing can also provide protection from complete enforcement and shutdown of the entire project. If a contractor is in noncompliance in one phase or zone of a site, that will be the only zone affected by enforcement. This approach can help to minimize liability exposure and protect the contractor financially (Deering, 2000b).

c. Practice site fingerprinting

Often areas of a construction site are unnecessarily cleared. Site fingerprinting involves clearing only those areas essential for completing construction activities, leaving other areas undisturbed. Additionally, the proposed limits of land disturbance should be physically marked off to ensure that only the land area required for buildings, roads, and other infrastructure is cleared. Existing vegetation, especially vegetation on steep slopes, should be avoided.

d. Locate potential pollutant sources away from steep slopes, waterbodies, and critical areas

Material stockpiles, borrow areas, access roads, and other land-disturbing activities can often be located away from critical areas such as steep slopes, highly erodible soils, and areas that drain directly into sensitive waterbodies.

e. Route construction traffic to avoid existing or newly planted vegetation

Where possible, construction traffic should be directed over areas that must be disturbed for other construction activity. This practice reduces the net total area that is cleared and susceptible to erosion.

f. Protect natural vegetation with fencing, tree armoring, and retaining walls or tree wells

Tree armoring protects tree trunks from being damaged by construction equipment. Fencing can also protect tree trunks, but it should be placed at the tree's drip line so that construction equipment is kept away from the tree. A tree's drip line is the minimum area around the tree in which the tree's root system should not be disturbed by cut, fill, or soil compaction caused by heavy equipment. When cutting or filling must be done near a tree, a retaining wall or tree well should be used to minimize the cutting of the tree's roots or the quantity of fill placed over the tree's roots.

g. Stockpile topsoil and reapply to revegetate site

Because of the high organic content of topsoil, it cannot be used as fill material or under pavement. After a site is cleared, the topsoil is typically removed. Since topsoil is essential to establish new vegetation, it should be stockpiled and then reapplied to the site for revegetation, if appropriate. Although topsoil salvaged from the existing site can often be used, it must meet certain standards, and topsoil might need to be imported onto the site if the existing topsoil is not adequate for establishing new vegetation.

h. Cover or stabilize soil stockpiles

Unprotected stockpiles are very prone to erosion, and therefore stockpiles must be protected. Small stockpiles can be covered with a tarp to prevent erosion. Large stockpiles should be stabilized by erosion blankets, seeding, and/or mulching.

i. Use wind erosion controls

Wind erosion controls limit the movement of dust from disturbed soil surfaces and include many different practices. Wind barriers block air currents and are effective in controlling soil blowing. Many different materials can be used as wind barriers, including solid board fences, snow fences, and bales of hay. Sprinkling moistens the soil surface with water and must be repeated as needed to be effective for preventing wind erosion (Delaware DNREC, 1989); however, applications must be monitored to prevent excessive runoff and erosion.

j. Intercept runoff above disturbed slopes and convey it to a permanent channel or storm drain

Earth dikes, perimeter dikes or swales, or diversions can be used to intercept and convey runoff from above disturbed areas to undisturbed areas or drainage systems. An earth dike is a temporary berm or ridge of compacted soil that channels water to a desired location. A perimeter dike/swale or diversion is a swale with a supporting ridge on the lower side that is constructed from the soil excavated from the adjoining swale (Delaware DNREC, 1989). These practices should be used to intercept flow from denuded areas or newly seeded areas and to keep clean runoff away from disturbed areas. The structures should be stabilized within 14 days of installation. A pipe slope drain, also known as a pipe drop structure, is a temporary pipe placed from the top of a slope to the bottom of the slope to convey concentrated runoff down the slope without causing erosion (Delaware DNREC, 1989).

k. On long or steep, disturbed, or man-made slopes, construct benches, terraces, or ditches at regular intervals to intercept runoff

Benches, terraces, or ditches break up a slope by providing areas of low slope in the reverse direction. This keeps water from proceeding down the slope at increasing volume and velocity. Instead, the flow is directed to a suitable outlet or protected drainage system. The frequency of benches, terraces, or ditches will depend on the erodibility of the soils, steepness and length of the slope, and rock outcrops. This practice should be used if there is a potential for erosion along the slope.

l. Use retaining walls

Often retaining walls can be used to decrease the steepness of a slope. If the steepness of a slope is reduced, the runoff velocity is decreased and, therefore, the erosion potential is decreased.

m. Provide linings for urban runoff conveyance channels

Often construction increases the velocity and volume of runoff, which causes erosion in newly constructed or existing urban runoff conveyance channels. If the runoff during or after construction will cause erosion in a channel, the channel should be lined or flow control practices installed. The first choice of lining should be grass or sod because it reduces runoff velocities and provides water quality benefits through filtration and infiltration. If the velocity in the channel would erode the grass or sod, turf reinforcement mats, riprap, concrete, or gabions can be used.

n. Use check dams

Check dams are small, temporary dams constructed across a swale or channel. They can be constructed using gravel, rock, gabions, or straw bales. They are used to reduce the velocity of concentrated flow and, therefore, to reduce erosion in a swale or channel.

o. Use seeding

Seeding establishes a vegetative cover on disturbed areas and is very effective in controlling soil erosion once a dense vegetative cover has been established. Seeding establishes permanent erosion control in a relatively short amount of time and has been shown to decrease solids load by 99 percent (CWP, 1997a). The three most common seeding methods are (1) broadcast seeding, in which seeds are scattered on the soil surface; (2) hydroseeding, in which seeds are sprayed on the surface of the soil with a slurry of water; and (3) drill seeding, in which a tractor-drawn implement injects seeds into the soil surface. Broadcast seeding is most appropriate for small areas and for augmenting sparse and patchy grass covers. Hydroseeding is often used for large areas (in excess of 5,000 square feet) and is typically combined with tackifiers, fertilizers, and fiber mulch. Drill seeding is expensive and is cost-effective only on sites greater than 2 acres. Bare soils should be seeded or otherwise stabilized within 15 calendar days after final grading. Denuded areas that are inactive and will be exposed to rain for 15 days or more should also be temporarily stabilized, usually by planting seeds and establishing vegetation during favorable seasons in areas where vegetation can be established. In very flat, nonsensitive areas with favorable soils, stabilization may involve simply seeding and fertilizing. The Soil Quality Institute (SQI, 2000) recommends that soils that have been compacted by grading should be broken up or tilled before vegetating.

To establish a vegetative cover, it is important to use seeds from adapted plant species and varieties that have a high germination capacity. Supplying essential plant nutrients, testing the soil for toxic materials, and applying an adequate amount of lime and fertilizer can overcome many unfavorable soil conditions and establish adequate vegetative cover. Specific information about seeds, various species, establishment techniques, and maintenance can be obtained from *Erosion Control & Conservation Plantings on Noncropland* (Landschoot, 1997) or a local Cooperative State Research, Education, and Extension Service (www.reeusda.gov) or Natural Resources Conservation Service (www.nrcs.usda.gov) office.

p. Use mulches

Newly established vegetation does not have as extensive a root system as existing vegetation and therefore is more prone to erosion, especially on steep slopes. Additional stabilization should be considered during the early stages of seeding. This extra stabilization can be accomplished using mulches or mulch mats, which can protect the disturbed area while vegetation becomes established.

Mulching involves applying plant residues or other suitable materials on disturbed soil surfaces. Mulches and mulch mats used include tacked straw, wood chips, and jute netting and are often covered by blankets or netting. Mulching alone should be used only for temporary protection of the soil surface or when permanent seeding is not feasible. The useful life of mulch varies with the material used and the amount of precipitation but is approximately 2 to 6 months. Mulching and/or sodding may be necessary as slopes become moderate to steep, as soils become more erosive, and as areas become more sensitive.

During the times of the year when vegetation cannot be established, mulch should be applied to moderate slopes and soils that are not highly erodible. On steep slopes or highly erodible soils, multiple mulching treatments should be used.

q. Use sodding for permanent stabilization

Sodding permanently stabilizes an area with a thick vegetative cover. Sodding provides immediate stabilization of an area and should be used in critical areas or where establishing permanent vegetation by seeding and mulching would be difficult. Sodding is also a preferred option when there is high erosion potential during the period of vegetative establishment from seeding. According to the Soil Quality Institute (SQI, 2000), soils that have been compacted by grading should be broken up or tilled before placing sod.

r. Install erosion control blankets

Turf reinforcement mats (TRMs) combine vegetative growth and synthetic materials to form a high-strength mat that helps prevent soil erosion in drainage areas and on steep slopes (USEPA, 1999). TRMs enhance the natural ability of vegetation to permanently protect soil from erosion. They are composed of interwoven layers of nondegradable geosynthetic materials such as polypropylene, nylon, and polyvinyl chloride netting, stitched together to form a three-dimensional matrix. They are thick and porous enough to allow for soil filling and retention.

In addition to providing scour protection, the mesh netting of TRMs is designed to enhance vegetative root and stem development. By protecting the soil from scouring forces and enhancing vegetative growth, TRMs can raise the threshold of natural vegetation to withstand higher hydraulic forces on stabilization slopes, streambanks, and channels. In addition to reducing flow velocities, the use of natural vegetation provides removal of particulates through sedimentation and soil infiltration and improves the aesthetics of a site.

In general, TRMs should not be used

- To prevent deep-seated slope failure due to causes other than surficial erosion.
- When anticipated hydraulic conditions are beyond the limits of TRMs and natural vegetation.
- Directly beneath drop outlets to dissipate impact force (although they can be used beyond the impact zone).
- Where wave height might exceed 1 foot (although they may be used to protect areas up-slope of the wave impact zone).

The performance of a TRM-lined conveyance system depends on the duration of the runoff event to which it is subjected. For short-term events, TRMs are typically effective at flow velocities of up to 15 feet per second and shear stresses of up to 8 lb/ft^2. However, specific high-performance

TRMs may be effective under more severe hydraulic conditions. Practitioners should check with manufacturers for the specifications and performance limits of different products.

In general, the installed cost of TRMs ranges from \$5.25/yd^2 to \$15.75/yd^2 (USEPA, 1999; adjusted to 2001 dollars using BLS, 2001). Factors influencing the cost of TRMs include

- The type of TRM material required.
- Site conditions, such as the underlying soils, the steepness of the slope, and other grading requirements.
- Installation-specific factors such as local construction costs.

In most cases, TRMs cost considerably less than concrete and riprap solutions. For example, a project in Aspen, Colorado, used more than 23,000 yd^2 of TRMs to line channels for a horse ranch development project (Theisen, 1996). The TRMs were installed at a cost of \$9.20/yd^2 (adjusted to 2001 dollars using BLS, 2001). This cost was substantially less than the \$20/yd^2 estimate for the rock riprap alternative.

s. Use chemical stabilization

Polyacrylamide (PAM) is a polymer produced mainly for agricultural use to control erosion and promote infiltration on irrigated lands (Sojka and Lentz, 1996). It is also being tested for use at construction sites to reduce erosion from disturbed areas (Aicardo, 1996; Roa-Espinosa et al., no date). When applied to soils, PAM binds to soil particles and forms a gel that decreases soil bulk density, absorbs water, and binds fine-grained soil particles. PAM is not only used for erosion control but is also employed in municipal water treatment, paper manufacturing, food and animal feed processing, cosmetics, friction reduction, mineral and coal processing, and textile production.

PAM is available in powder form or as aqueous concentrate, blocks and cubes, or emulsified concentrate; each type has benefits and drawbacks that alter its applicability in different settings and by different application methods. PAM costs \$1.30 to \$38.50 per pound (Entry and Sojka, 1999; Sojka and Lentz, 1996; updated to 2001 dollars with BLS, 2001) and has been shown to achieve a 77 to 93 percent reduction in sediment loss from disturbed sites (Roa-Espinosa et al., no date).

Application of PAM improves surface water quality by decreasing suspended solids and the phosphorus, nitrogen, pesticides, pathogens, salts, metals, and BOD usually associated with sediment loading. However, PAM may detrimentally affect ground water quality by increased leaching of nutrients, pesticides, and pathogens as a result of improved infiltration. Although careful application of PAM at prescribed rates can partially mitigate its negative effects, the effects of PAM application on water quality and wildlife are still unknown.

Questions have arisen as to PAM's environmental toxicity. Anionic PAM, the form found most often in erosion control products, has not been proven to be toxic to aquatic, soil, or plant species. The molecule is too large to cross membranes, so it is not absorbed by the gastrointestinal tract, is not metabolized, and does not bioaccumulate in living tissue. Cationic

PAM, although not of major concern for erosion control applications, has been shown to be toxic to fish because of its affinity to anionic hemoglobin in the gills.

Most of the concern for PAM toxicity has arisen because of acrylamide (AMD), the monomer associated with PAM and a contaminant of the PAM manufacturing process. AMD has been shown to be both a neurotoxin and a carcinogen in laboratory experiments. Current regulations require that AMD not exceed 0.05 percent in PAM products. Although there seems to be little risk from AMD as a result of prescribed application of PAM, it is uncertain what effects might result from spills, overapplication, or other accidents.

Minton and Benedict (1999) examined the use of polymers to clarify construction site runoff that had been detained on-site. The study was undertaken because traditional management practices did not reduce turbidity and sediments to the level desired by the city of Redmond, Washington, or to the level required to meet receiving water standards of the state of Washington, especially since several streams within the city limits had salmon fisheries.

Minton and Benedict used a multi-phase system to remove sediments and associated pollutants from construction site runoff. The first phase involved collection of storm water at interception points using the permanent drainage system installed early in the construction period and/or building excavations (see Figure 5.1). The collected runoff was then diverted, usually by pumping, to one or more storage ponds. (The permanent postdevelopment detention and treatment system, as required by local regulations, could be used for this storage during the construction phase given that it has sufficient capacity to handle site runoff, with supplemental storage provided as necessary.) The water was then pH-adjusted to optimize flocculation based on the particular polymer used. Finally, the water was pumped to one of two treatment cells, during which time the polymer was added (upstream of the transfer pump to maximize mixing and flocculation).

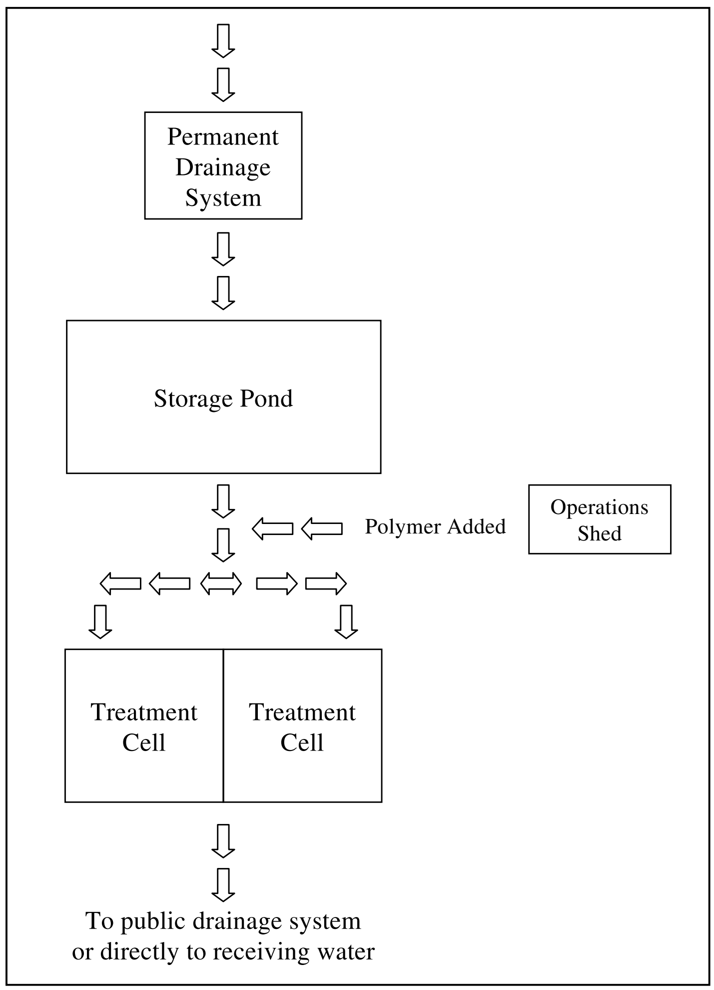

Figure 5.1: Schematic of the basic polymer treatment system (Minton and Benedict, 1999).

Two treatment cells were used so that settling could take place in one cell while runoff was pumped into the second cell. The floc was allowed to settle for a few hours to several days, with the most common practice being an overnight settling period. The duration of settling depended on the need to clear the treatment cell for further treatment. Water was discharged to the public discharge system using a float device with a 4-inch discharge system and a 12-inch clearance to keep the float from picking up settled sediment. Alternatively, the clarified water could be discharged to the sanitary sewer if problems arose in the treatment system.

Table 5.4 presents performance data for the six sites studied. Median turbidities of the untreated storm water varied between sites. These differences might have been caused by differences in the percentage of soil fines, the slopes, and the application of standard management practices.

Table 5.4: Summary of operating performance data for six test sites (Minton and Benedict, 1999)[a].

	Polymer Dosage		Influent Turbidity		Effluent Turbidity		pH Control	
Site	**Range**	**Median**	**Range**	**Median**	**Range**	**Median**	**Frequency[b]**	**Type[c]**
1	25–250	75	12–2,960	200	1–45	6	45%	acid
2	10–200	100	31–4,700	2,000	1.9–39	11	16%	both
3	50–>100	100	12.9–900	150	0.5–45	7	18%	soda ash
4	50–200	100	8–4,000	400	<1–32.5	6	0%	–
5	300–400	350	2,780–17,000	14,000	0.8–23	8	97%	soda ash
6	85–140	110	17–6,650	117	1.7–18	4	85%	both

[a] Excludes the start-up period when effluent turbidities were not yet at desired levels (usually a week or two for most sites).
[b] Approximate percentage of the number of operating days on which pH adjustment occurred.
[c] Most frequent form of pH adjustment: soda ash or sulfuric acid.

Developers at the test sites reported costs to be between 0.8 and 1.5 percent of the total construction cost, while another developer reported an approximate cost of $1/ft^2 for the treatment system. Temporary storage and treatment ponds, as well as piping, pumps, and other equipment, accounted for the majority of the costs associated with polymer treatment.

t. Use wildflower cover

Because of the hardy drought-resistant nature of wildflowers, they may be more beneficial as an erosion control practice than turf grass. Though not as dense as turfgrass, wildflower thatches and associated grasses are expected to be as effective in erosion control and contaminant absorption. An additional benefit of wildflower thatches is that they provide habitat for wildlife, including insects and small mammals. Because thatches of wildflowers do not need fertilizers, pesticides, or herbicides and watering is minimal, implementation of this practice may result in cost savings. A wildflower stand requires several years to become established, but maintenance requirements are minimal once established.

3. Sediment Control Practices

Sediment controls capture sediment that is transported in runoff. Filtration and gravitational settling during detention are the main processes used to remove sediment from urban runoff. Table 5.5 shows cost and effectiveness information for several sediment control practices.

a. Install sediment basins

Sediment basins, also known as silt basins, are engineered impoundment structures that allow sediment to settle out of the urban runoff. They are installed prior to full-scale grading and remain in place until the disturbed portions of the drainage area are fully stabilized. They are generally located at the low point of sites, away from construction traffic, where they will be able to trap sediment-laden runoff. Basin dewatering is achieved either through a single riser and drainage hole leading to a suitable outlet on the downstream side of the embankment or through the gravel of the rock dam. In both cases, water is released at a substantially slower rate than would be possible without the control structure.

Table 5.5: Cost and effectiveness for selected sediment control practices.

Practice	Percent TSS Removal	Effectiveness References	Cost (2001 dollars[a])	Cost References
Sediment basin	Average: 70% Range: 42%-100%	CWP, 1997d; Millen et al., No date; USEPA, 1993	For 50,000 ft^3 of storage space: Average: $0.73/$ft^3$ Range: $0.24–$1.58/ft^3 storage For more than 50,000 ft^3 of storage space: Average: $0.36/$ft^3$ Range: $0.12–$0.48/ft^3 storage	USEPA, 1993
Modified risers and skimmers	Single orifice: 83% Perforated risers: 68%–94% Perforated risers w/filter fabric: 79% Skimmer: 83%–97%	Jarrett, 1999, Schueler, 1997	NA	NA
Sediment trap	50%–70%	Stahre and Urbonas, 1990	Average: $0.73/$ft^3$ storage Range: $0.24–$2.42/ft^3 storage Maintenance costs: 20% of installation costs	Brown and Schueler, 1997; USEPA, 1993
Silt fence	40%–100%	Barrett et al., 1995; Wishowski et al., 1998; CWP, 1997e	$3.50–$9.10/linear ft	SWRPC, 1991; USEPA, 1992
Inlet protection	NA	NA	$60–$120/inlet	USEPA, 1993
Stabilized construction entrance	NA	NA	Without wash rack: Average: $2,400/entrance Range: $1,200–$4,800/entrance With wash rack: Average: $3,600/entrance Range: $1,200–$6,000/entrance	USEPA, 1993
Vegetated filter strips	75-ft width: 54% 15-ft width: 84%	Yu et al., 1993	Established from existing vegetation: $0 Established from seed: Average: $485/acre Range: $250–$1,200/acre Established from sod: Average: $13,000/acre Range: $5,500–$58,000/acre Note: Values do not include land costs or costs associated with installing a level spreader	USEPA, 1993

[a]Costs adjusted for inflation using the Consumer Pricing Index (BLS, 2001). NA: Not available

The following are general specifications for sediment basin design criteria as presented in Schueler (1997):

- Provide 1,800 to 3,600 cubic feet of storage per contributing acre (a number of states, including Maryland, Pennsylvania, Georgia, and Delaware, recently increased the storage requirement to 3,600 ft^3 or more [CWP, 1997b]).
- Surface area equivalent to 1 percent of drainage area (optional, seldom required).
- Riser with spillway capacity of 0.2 ft^3/s/ac of drainage area (peak discharge for 2-year storm with 1-foot freeboard).
- Length-to-width ratio of 2 or greater.
- Basin side slopes no steeper than 2:1 (h:v).
- Safety fencing, perforated riser, dewatering (optional, seldom required).

Sediment basins can be classified as either temporary or permanent structures, depending on the length of service of the structure. If they are designed to function for less than 36 months, they are classified as temporary; otherwise, they are considered permanent. Temporary sediment basins can also be converted into permanent urban runoff management ponds. When sediment basins are designed as permanent structures, they must meet all standards for wet ponds. It is important to note that even the best-designed sediment basin seldom exceeds 60 to 75 percent TSS removal. This number should be taken into consideration when selecting a sediment control practice.

b. Use modified risers and skimmers

Because traditional riser designs provide little treatment to remove sediments, efforts have been made to improve the design of sediment basins to facilitate greater pollutant removal. Modifications to traditional designs that improve sediment removal efficiency include using perforated risers or perforated risers wrapped in a gravel jacket or filter fabric. An alternative to the riser is a skimmer device that floats on the surface of water in the basin (Faircloth, 1999). The skimmer is made of a straight section of PVC pipe equipped with a float and attached with a flexible coupling to a flow-controlled outlet at the base of the riser. Because the skimmer floats, it rises and falls with the level of water in the basin and drains only the cleanest top layer of runoff. Also, because it lowers to the bottom of the basin, it is capable of more thorough dewatering than a traditional riser, thereby restoring the maximum runoff storage capacity. The sediment-removal performance of basins equipped with skimmer dewatering devices has been shown to be nearly 97 percent for a simulated 2-year, 24-hour design storm event (Schueler, 1997).

Jarrett (1999) tested the sediment-removal effectiveness of several types of basins (outlet placement, deeper/shallower, barrier/no barrier) and outlet designs, including perforated risers (with and without filter fabric), single-orifice risers, and several sizes of skimmers. Table 5.6 shows the sediment retention efficiency results of Jarrett's different treatments.

Jarrett drew the following conclusions from his study:

- Perforated risers and single-orifice risers had similar sediment losses.
- Deeper permanent pools resulted in greater sediment removal.
- Sediment loss was attributed partly to resuspension and partly to basin erosion.
- Perforated risers resulted in 1.8 times greater sediment loss than skimmers when the outlet devices were placed in the principal spillway.
- Barriers that trisect basin volume reduced sediment loss when perforated risers were used but did not reduce sediment loss when skimmers were used.
- Silt-sized particles were most likely to be lost from sediment basins.
- Longer dewatering time resulted in less overall sediment loss.

Table 5.6: Sediment retention efficiency[a] of sediment basins (Jarrett, 1999).

Treatment[b]	Outlet Control	Basin Size (m^3)	Hydrograph Volume Injected (m^3)	Emergency Spillway Used	Barrier Used	Dewatering Time (hr)	Permanent Pool Depth (m)	Sediment Loss (kg)	Sediment Retention Efficiency (%)
1	Perforated riser	140	100	No	No	24	0.15	32	79
2	Single orifice	140	100	No	No	24	0.15	26	83
5	Perforated Riser	140	100	No	No	24	0.46	1	92
6	Perforated riser with filter fabric	140	100	No	No	?	0.15	32	79
7	Skimmer	140	100	No	No	24	0.15	17	89
8	Perforated riser	140	100	No	Yes	24	0.15	24	84
9	Skimmer	140	100	No	No	24	0.15	20	87
10	Perforated riser	140	100	No	No	6	0.15	49	68
10	Perforated riser	140	100	No	No	168	0.15	9	94
10	Skimmer	140	100	No	No	6	0.15	22	86
10	Skimmer	140	100	No	No	168	0.15	5	97
11	Perforated riser	140	100	Yes	No	24	0.15	44	71
11	Skimmer	140	100	Yes	No	24	0.15	26	83
11a	Perforated riser	50	50	No	No	24	0.15	22	86
11a	Skimmer	50	50	No	No	24	0.15	7	95
3,4	Resuspension equaled 24% of sediment lost from basin								
3,4	Erosion from basin sides and bottom equaled 24% of sediment lost from basin								
1	Basin suspension was completely mixed during hydrograph inflow								
1	Basin suspension quickly stratified when inflow energy was reduced to zero								

[a]The 90 percent and greater TSS removal rates might be difficult to achieve in the field because (1) sizing criteria are much higher in Pennsylvania; (2) these were laboratory, not field, tests; and (3) maintenance was above average.
[b]In all treatments, effective soil injected was 154 kg.

c. Install sediment traps

Sediment traps are small impoundments that allow sediment to settle out of runoff water. They are typically installed in a drainageway or other point of discharge from a disturbed area. Temporary diversions can be used to direct runoff to the sediment trap. Sediment traps are ideal for sites 1 acre and smaller and should not be used for areas greater than 5 acres. They typically have a useful life of approximately 18 to 24 months. A sediment trap should be designed to maximize surface area for infiltration and sediment settling. This design increases the effectiveness of the trap and decreases the likeliness of backup during and after periods of high runoff intensity. The approximate storage capacity of each trap should be at least 1800 ft^3/acre disturbed draining into the trap (Smolen et al., 1988). (A number of states, including Maryland, Pennsylvania, Georgia, and Delaware, recently increased the storage requirement to 3,600 ft^3 or more [CWP, 1997b].)

d. Use silt fence

Silt fence, also known as filter fabric fence, is available in several mesh sizes from many manufacturers. Sediment is filtered out as runoff flows through the fabric. Such fences should be used only where there is sheet flow (no concentrated flow), and the maximum drainage area to the fence should be 0.5 acre or less per 100 feet of fence. To ensure sheet flow, a gravel collar or level spreader can be used upslope of the fence. Many types of fabrics are available commercially. The characteristics that determine a fence's effectiveness include filtration efficiency, permeability, tensile strength, tear strength, ultraviolet resistance, pH effects, and creep resistance.

The longevity of silt fences depends heavily on proper installation and maintenance. CWP (1997d) identified several conditions that limit the effectiveness of silt fences:

- The length of the slope exceeds 50 feet for slopes of 5 to 10 percent, 25 feet for slopes of 10 to 20 percent, or 15 feet for slopes greater than 20 percent.
- The silt fence is not aligned parallel to the slope contours.
- The edges of the silt fence are not curved uphill, allowing flow to bypass the fence.
- The contributing length to the fence is greater than 100 feet.
- The fence receives concentrated flow without reinforcement.
- The fence was installed below an outlet pipe or weir.
- The silt fence is upslope of the exposed area.
- The silt fence alignment does not consider construction traffic.
- Sediment deposits behind the silt fence reduce capacity and increase breach potential.
- The alignment of the silt fence mirrors the property line or limits of disturbance but does not reflect ESC needs.

These conditions can be avoided with proper siting, installation, and maintenance. Silt fences typically have a useful life of approximately 6 to 12 months.

EvTEC tests a static slicing silt fence installer

A static slicing silt fence installer was recently tested by EPA's Environmental Technology Evaluation Center (EvTEC, 2001). The goal of the testing was to determine if slicing was as better method than trenching with respect to performance, cost, and ease of use. The static slicing method, an alternative to traditional trenching methods, involves inserting a narrow custom-shaped blade at least 10 inches into the ground and simultaneously pulling silt fence fabric into the opening created as the blade is pulled through the ground. The tip of the blade is designed to slightly disrupt soil upward, preventing horizontal compaction of the soil and simultaneously creating an optimum soil condition for future mechanical compaction. Compaction follows using a tire on the tractor that pulls the slicing machine. Post-setting and driving, followed with attaching the fabric to the post, finalizes the installation.

EvTEC found that the slicer performed as well as or better than the best trenching method and was superior to less stringent methods of trenching. Slicing took less time (1.75 to 4 times faster) and was therefore cost-effective because of man-hour savings. The slicing method prevented runoff seepage and blowout better than most trenching methods and performed as well as the best trenching method. Overall, the static slicing method offers several advantages over traditional trenching methods, including maneuverability, minimal soil-handling and manual labor, consistent depth and compaction, and ease of installation in windy conditions, on steep side slopes, through rocky soils, and in saturated conditions.

e. Establish inlet protection

Inlet protection consists of a barrier placed around a storm drain inlet, which traps sediment before it enters the storm sewer system. There are five basic types of inlet protection structures: silt fence barriers, straw bale inlet barriers, block and gravel drop inlet filters, block and gravel curb inlet filters, and various excavated drop inlet protection measures (NAHB, 1995). The structures should be placed at the perimeter of the inlet structure. Inlet protection is appropriate for small drainage areas (1 acre or less) and can be used during rainy seasons (California Regional Water Quality Control Board, 1999). The structures can handle sheet flow with velocities less than 0.014 m^3/s; block and gravel barriers should be used in cases where concentrated flows exceed 0.014 m^3/s.

f. Designate and reinforce construction entrances

A construction entrance is a pad of gravel or rock over filter cloth located where traffic enters and leaves a construction site. As construction vehicles drive over the gravel, mud and sediment are collected from the vehicles' wheels. To maximize the effectiveness of this practice, the rock pad should be at least 50 feet long and 10 to 12 feet wide. The gravel should be 1- to 2-inch aggregate 6 inches deep laid over a layer of filter fabric. Maintenance might include pressure-washing the gravel to remove accumulated sediments and adding more rock to maintain adequate thickness. Runoff from this entrance should be treated before exiting the site. This practice can be combined with a designated truck wash-down station to ensure sediment is not transported off-site.

g. Install vegetated filter strips

Vegetated filter strips are low-gradient vegetated areas that filter overland sheet flow. Runoff must be evenly distributed across the filter strip. Channelized flows decrease the effectiveness of filter strips. Level spreading devices are often used to distribute the runoff evenly across the strip (Dillaha et al., 1989).

Vegetated filter strips should have relatively low slopes and adequate length and should be planted with erosion-resistant plant species. The main factors that influence the removal efficiency are the vegetation type, soil infiltration rate, and flow depth and travel time. These factors are dependent on the contributing drainage area, slope of strip, degree and type of vegetative cover, and strip length. Maintenance requirements for vegetated filter strips include sediment removal and inspections to ensure that dense, vigorous vegetation is established and concentrated flows do not occur.

h. Use vegetated buffers

Like filter strips, vegetated buffers provide a physical separation between a construction site and a waterbody. The difference between a filter strip and a vegetated buffer area is that a filter strip is an engineered device, whereas a buffer is a naturally occurring filter system. Vegetated buffers remove nutrients and other pollutants from runoff, trap sediments, and shade the waterbody to optimize light and temperature conditions for aquatic plants and animals (Welsch, no date). Preservation of vegetation for a buffer should be planned before any site-disturbing activities begin so as to minimize the impact of construction activities on existing vegetation. Trees should be clearly marked at the dripline to preserve them and to protect them from ground disturbances around the base of the tree.

Proper maintenance of buffer vegetation is important. Maintenance requirements depend on the plant species chosen, soil types, and climatic conditions. Maintenance activities typically include fertilizing, liming, irrigating, pruning, controlling weeds and pests, and repairing protective markers (e.g., fluorescent fences and flags).

4. Develop and Implement Programs to Control Chemicals and Other Construction Materials

a. Develop and implement a materials management program

Areas where materials are stored at a construction site can be sources of runoff contamination due to poor housekeeping and accidental spills. Improving storage and material management practices will help minimize exposure and risk. Erodible or potentially hazardous materials should be stored in such a manner as to prevent contact with rainfall or runoff. In general, materials should be stored in a secure, dry, covered area that is equipped with an impermeable floor and berms to prevent spills from reaching surrounding soils, ground water, and surface water. Conducting an inventory of all materials used on-site and assessing the potential they pose for contact with runoff will help in implementing effective controls.

Properly store, handle, and apply pesticides. In general, pesticides should be used only when absolutely necessary. Instructions listed on the packaging should be followed when using, handling, or disposing of these chemicals. Consideration should be given to local regulations that may govern the use or disposal of pesticide chemicals or their containers. To reduce the risk of contaminating runoff, the following practices should be implemented:

- Store pesticides in a secure, dry, covered area that has an impermeable floor.
- Provide curbs or dikes around the storage area to prevent spills and leaks from reaching unprotected areas.
- Provide site personnel with the proper pesticide spill response training and have adequate measures on-site to contain and clean up pesticide spills.
- Strictly follow recommended application rates and application methods.
- Handle pesticide wastes appropriately. Many pesticides are considered hazardous wastes when they are disposed of. Pesticide wastes should be managed as required by all applicable waste regulations.

Properly store, handle, and apply petroleum products. The following practices can help to reduce the risk of runoff contamination from petroleum products:

- Store petroleum products in designated areas that are covered, have impermeable floors, and are surrounded with dikes, berms, or absorbent pads to contain any spills.
- Provide site personnel with the proper spill response training and have adequate measures on-site to contain and clean up petroleum spills. Store spill cleanup equipment in fuel storage areas or on board maintenance and fueling vehicles.
- Conduct periodic preventive maintenance of on-site equipment and vehicles to prevent leaks.

Properly store, handle, and apply fertilizers and detergents. A number of steps can be taken to reduce the risks of nutrient pollution:

- Minimize the use of fertilizers and detergents. Determine the smallest amounts needed for the tasks at hand and avoid using unnecessary amounts. Apply fertilizers and use detergents only in the recommended manner and never in amounts greater than those recommended.
- When applying fertilizers to soil, apply them at a depth of 2 to 6 inches and not on the surface. This approach will limit the contact between runoff and nutrients.
- Apply fertilizers more frequently but at lower application rates.
- Implement appropriate erosion and sediment control practices that will control and limit the amount of nutrients leaving the site due to attachment to soil particles.

- Conduct washing/cleaning operations in designated areas that are equipped to contain washwater and prevent it from being discharged to the site runoff collection and conveyance system.
- Do not mix surplus products together unless following specific instructions from the manufacturer.

Properly store, handle, and apply hazardous products. Most problems associated with the disposal of hazardous materials are the result of carelessness, not following recommended procedures, or not using common sense. The following suggestions are meant to provide general guidance for disposal of hazardous materials:

- Determine what hazardous materials are being used on-site and which hazardous waste streams, if any, are generated as a result of construction activities. Once all of the hazardous materials used and hazardous wastes generated are identified, it is possible to implement an appropriate waste management and disposal strategy.
- Know the applicable hazardous waste regulations and the associated requirements for storing, marking, and disposing of wastes. Someone on-site should be trained to properly manage hazardous wastes. If waste disposal obligations are not clearly understood, contact the correct regulatory agency to find out what specific requirements must be followed.
- Use as much of a product as possible before disposing of containers. Containers that are not empty but have been stored for disposal can be sources of drips, leaks, or spills and can contaminate landfills or other disposal areas.
- Do not remove the original product label from the container. It contains important use, safety, and disposal information about the product.

b. Develop and implement a spill control plan

Construction sites should be equipped with suitable equipment to contain and clean up spills of hazardous materials in the areas where the materials are stored or used. Accidental spills of materials used at construction sites can be sources of runoff pollution if not addressed appropriately. All spills should be cleaned up immediately after they occur. Creation of a site-specific spill control and response plan in combination with spill response training for designated on-site personnel can be effective in dealing with accidental spills and preventing the contamination of soil, water, and runoff. Preparation of a spill containment, control, and countermeasures (SPCC) plan might be required to meet regulatory requirements (e.g., requirements regarding storage of specified chemicals above certain volume thresholds). Site managers should be aware of all applicable requirements and should contact regulatory authorities if requirements are not known.

Even if a formal plan is not required, preparing one is a good idea. In general, an SPCC plan should include guidance to site personnel on

- Proper notification when a spill occurs.
- Site responsibility with respect to addressing the cleanup of a spill.
- Stopping the source of a spill.
- Cleaning up a spill.
- Proper disposal of materials contaminated by the spill.
- Location of spill response equipment programs.
- Training program for designated on-site personnel.

A periodic spill "fire drill" should be conducted to help train personnel on proper responses to spill events and to keep response actions fresh in the minds of personnel.

c. Develop and implement a waste disposal program

Implementation of good waste disposal practices at construction sites can help to significantly reduce the potential for runoff contamination. Wastes generated at construction sites can include surplus maintenance chemicals, refuse building materials, hazardous wastes, or contaminated soil and spill cleanup materials. General practices to manage such wastes include solid waste disposal, recycling, hazardous waste management, and spill prevention and cleanup measures.

(1) *Develop procedures for disposal of construction wastes*. Construction projects can generate a significant amount of what is commonly referred to as "construction wastes." Such wastes are unique to the activity and might include the following:

- Trees and shrubs removed during clearing and grubbing.
- Packaging materials such as wood, paper, plastic, and polystyrene.
- Scrap or surplus building materials such as scrap metal, rubber, plastic, glass, and masonry.
- Paints and paint thinners.
- Demolition debris such as concrete rubble, asphalt, and brick.

To ensure proper disposal of construction wastes, the following steps should be followed:

- Select a designated on-site waste collection area.
- Provide an adequate number of containers with lids or covers that can be placed over the containers prior to rainfall.
- Locate containers in a covered area when possible.
- Arrange for waste collection before containers overflow.

– Explore recycling options for specific wastes generated at the site. Wastes such as used oil, used solvents, and construction debris can often be reclaimed or recycled, thereby reducing the amount of waste actually requiring permanent disposal. Numerous companies can provide recycling services, including the provision and maintenance of on-site recycling containers.

– Implement appropriate spill response procedures immediately when a spill does occur.

– Plan for additional containers and more frequent pickups during the demolition phase of construction activities.

– Ensure that all construction wastes are disposed of at facilities authorized to receive such wastes.

(2) *Develop procedures for disposal of hazardous products*. The correct method of disposal of hazardous products varies with the product used. Follow the manufacturer's recommended method as printed on the product label.

(3) *Develop procedures for disposal of contaminated soils*. Options for disposal of contaminated soil depend on the nature of the soil contamination present. Under no circumstances should contaminated soils be disposed of in adjoining properties or in swamps or other wetlands because they will still pose a threat to surface and ground water. The appropriate solid and/or hazardous waste regulatory agency should be contacted concerning the proper procedures for characterizing, removing, and disposing of contaminated soil. Typically, contaminated soils can either be excavated and removed or cleaned on-site. In situ techniques include applying chemicals that break down or neutralize the contaminant, venting or sparging the soil to oxidize the contaminant, and using biological treatment to metabolize and destroy the contaminant.

(4) *Develop procedures for disposal of concrete truck waste*. Many construction projects include the use of concrete. Usually the concrete is mixed off-site and delivered to the project by truck. The concrete is poured and a residual amount of concrete remains in the truck or the concrete is found to be unacceptable and is rejected by the construction inspector or foreman. The truck may be cleaned of residual concrete on-site. Excess concrete and wash water should be disposed of in a manner that prevents contact between these materials and runoff. For example, dikes could be constructed around the area to contain these materials until they harden, at which time they can be properly disposed of.

(5) *Develop procedures for disposal of sandblasting grits*. Sandblasting is frequently used to remove paint and dirt from surfaces. The grit generated contains both the spent blasting grit (commonly sand or steel granules) and the particles of paint or dirt removed from the surface. Sandblasting residue can be a hazardous waste if the material removed contains hazardous metals such as cadmium, lead, and chromium, which are sometimes found in paints. For this reason, sandblasting residue should not be allowed to be released to the ground or discharged to a storm sewer or sanitary sewer, where it can cause soil or water contamination. Instead, it should be evaluated to determine whether it constitutes a hazardous waste. If determined to be a hazardous waste, it should be properly handled and disposed of; if not a hazardous

waste, it should be properly managed and disposed of as a solid waste. Dumping wastes into sewers and other drainage channels is illegal and can result in fines or job shutdown (USEPA, 1993).

(6) *Develop procedures for disposal of sanitary wastes.* Construction sites usually are equipped with temporary sanitary facilities such as portable toilets for on-site personnel. Sanitary wastes can also be disposed of through septic systems or sanitary sewers. The type of facilities used on-site will dictate the appropriate management practices used to deal with the wastes. Domestic waste haulers should be contracted to regularly remove the sanitary and septic wastes and to maintain the facilities in good working condition. This maintenance will help to prevent overloading of the system, which could result in discharges in runoff. All septic systems should be installed, operated, and maintained in accordance with appropriate regulations. Any discharges to the sanitary sewer systems should be done in accordance with local sewer authority regulations.

Information Resources

Storm Water Management for Construction Activities: Developing Pollution Prevention Plans and Best Management Practices (USEPA, 1992), published by EPA's Office of Wastewater Management, provides summary guidance on the development of storm water pollution prevention plans and helps users select appropriate management practices to control erosion and sediment loss resulting from construction activities. It was designed to provide technical support for construction activities that are subject to pollution prevention requirements under NPDES permits for storm water point source discharges. This document can be viewed in PDF format at *www.epa.gov/npdes/pubs/owm0307.pdf* or it can be ordered from the National Service Center for Environmental Publications (NSCEP) at *www.epa.gov/ncepihom/index.htm* or by calling 513-489-8190 (Publication # EPA 833-R-92-001).

The city of Knoxville, Tennessee, developed a manual that describes storm water management practices that the city recommends. The manual includes an introduction to storm water management practices, a discussion of the theory of erosion control, steps for selecting practices, and detailed fact sheets for each practice that include design, inspection, and maintenance information. The fact sheets cover four subject areas: activities and methods, erosion and sediment, industrial and commercial, and storm water treatment. The manual can be downloaded in PDF format at *www.ci.knoxville.tn.us/engineering/bmp_manual*.

The Delaware Department of Natural Resources and Environmental Control has assembled course materials and associated standards and specifications that contain descriptions of Delaware's erosion and sediment control and runoff control BMPs as well as their certification requirements for contractors. These materials, entitled *Sediment and Stormwater Management Certified Construction Reviewer Course and associated Delaware State and DOT Standards/Specifications*, can be obtained by calling 302-739-4411.

The North Carolina Department of Environment, Health, and Natural Resources (NCDEHNR, no date) developed a suite of references pertaining to erosion and sediment control, including the *Erosion and Sediment Control Planning and Design Manual*, which provides extensive details and procedures for developing site-specific erosion and sedimentation control plans. The *North Carolina Erosion and Sediment Control Field Manual* is a conveniently sized field reference for construction and installation of erosion and sedimentation control measures and devices (does not include design charts). The *North Carolina Sediment Control Inspector's Guide* explains how to conduct inspections and evaluate projects, what to look for, and how to interact with customers. The *North Carolina Erosion and Sediment Control Practices: Video Modules* demonstrate the actual construction of 12 of the most commonly installed erosion and sediment control measures. Information for purchasing these materials can be found at the NCDEHNR web site at *www.dlr.enr.state.nc.us/eropubs.html*.

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